An approach to increasing the competitiveness of logistics equipment by optimizing the ergonomic requirements

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Abstract: **This work shows the creation of a methodology for evaluating the ergonomic requirements in logistics equipment, taking into account the operating time i.e. building a machine for a particular logistics system so as to reduce the cost and performance of low ergonomics and increase competitiveness.**

Keywords: **product quality, product strategy, competitiveness, ergonomic requirements, emotional model, innovation, logistics equipment**

JEL: **M1, M11**

I. Introduction

The modern world market is characterized by its orientation to the client. This led to higher individual requirements for the design, production and marketing of any product, to high competition, optimized ratio between price and quality and complete satisfaction of customer requirements. Rigor of modern consumers is growing rapidly, shortening life cycle of products and increasing service levels.

Globalization and economic crisis put competition as the most important economic problem. In (Boeva B.2012) corporate governance and international competitiveness are analyzed by justifications (theoretical and empirical) that corporate governance is a key factor for the formation of the level of competitiveness of the company. In Bulgarian literature there are also a number of authors who deal with important aspects of competitiveness and its manifestation, such as: Mitko Dimitrov, Iveta Chobanova, Mladen Velev, Ivan Angelov, Manol Ribov Joseph Iliev, Todor Nenov, Georgi Mishev and others. (Sterev N. 2012)

The present paper focuses on product competitiveness. It is a "combination of quality and value characteristics of the product, securing its market advantage over competitors' products in meeting the specific requirements". The assessment of the competitiveness of the product can be reduced to the following variables:

- product quality features - cover all those perceived by the consumers properties and characteristics of the product, which determine the assessment of the consumer for product quality;
- functional indicators (including product ergonomic factors such as hygienic, physiological, psycho-physiological, psychological indicators, etc.);
- economic characteristics of product - cover these product characteristics that determine the subjective assessment of the consumer to the product value.(Sterev N. 2012).

In (www.temionline.com) a methodology is considered which clarifies the main steps to be followed to assess the current competitiveness of the company. It is reported there that ergonomics is an essential element of competitiveness.

There are various works on the issue of ergonomics in the workplace and working environment (Zacheva-Hristova N. 2014; Kostova, D. and V. Petrova 2013; etc.) but they are addressing the question for the entire work shift.

Tangible competition consists in comparing the parameters of various logistics equipment brands of the same model with the wishes of the client determined by market requirements. The requirements for logistical machine dictate its architecture. These requirements are determined also by client parameters that define the usefulness as well. These parameters are dynamic and can be changed by the customer within certain limits. The current paper studies the technical competitiveness (Nikolov A, N. Kazakov, 2013).

It is known that the logistical equipment and the service of the production process form 70% of total production costs (Ballow R.1992) but the use of logistics technology in a logistics process is not always 100% of the production time. It strongly depends on the mode of operation of this equipment. In many cases this time is below 50%, which is related to the impact on human (operator). The question arises as to what extent the norms and standards of ergonomics should be realized as a function of time of use so that the machines be as cheap and competitive, without any effect on the efficiency of the staff. In this work logistics equipment will refer to the material handling and warehouse equipment operated by an operator i.e. electric and gas forklifts, AS/RS systems, cranes, container trucks and others.

On the other hand the requirements of ergonomics define the area in which a machine is to be designed and

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influence strongly the design of the logistics machine and the nature of the logistics process in which it participates. These requirements are set out in a number of international and national standards and regulations. They define the limits in the preparation of systems design and analysis in logistics and construction of the machine architecture. Therefore during the design stage it is important to find the optimal ergonomic values to achieve a competitive model. Moreover, logistics requires the creation of the right machines for each specific logistics process (Kazakov N. 2000).

The objective of this work is the creation of a methodology for evaluating the ergonomic requirements in logistics equipment, taking into account the operating time i.e. building a machine for a particular logistics system to reduce the cost and increase competitiveness.

A different study exists that determine the operability of a person by taking into account the statutory breaks. Figure 1 shows a graph of the work of a person with a single break for lunch (Shirokov A.2006).

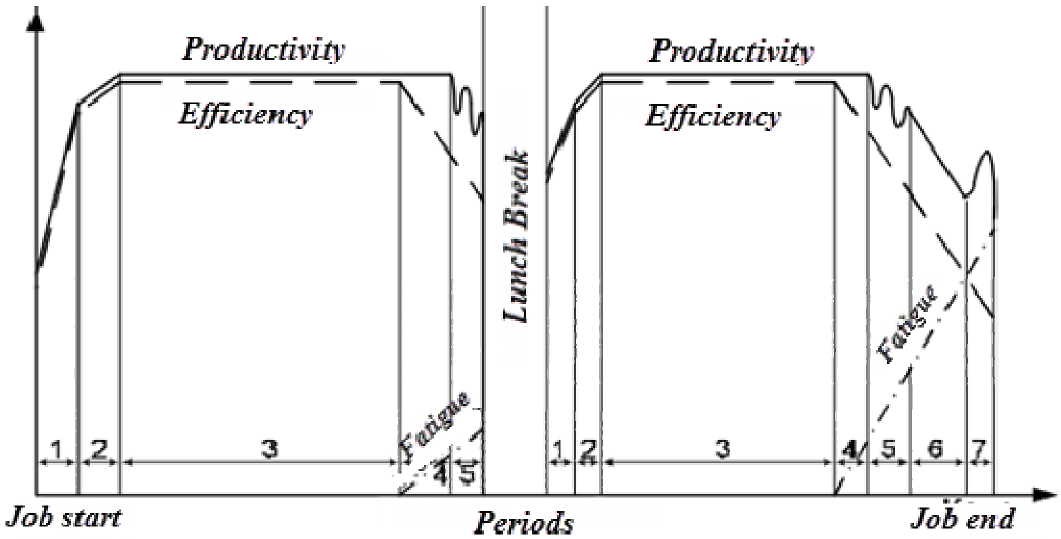

Figure 1. Working efficiency of a person with interruption: 1 fast-growing efficiency; 2-growing; 3 -constant; 4- fatigue compensating; 5 -unsustainable compensation; 6-declining; 7-final

II. METHODOLOGY FOR ASSESSING ERGONOMIC REQUIREMENT

The task in this work deals with case when n number of interruptions (n = 1,2, ..., N) exist that are determined by the nature of the workflow and fatigue of the operator of the logistics machine.

The structural scheme of interaction of the system is (figure 2):

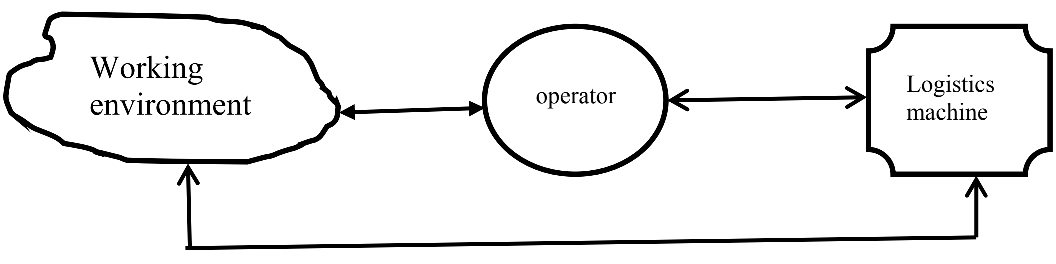

Figure 2. Structural scheme of the system

The proposed methodology is based on the emotional model and consists of six modules (Figure 3).

1. **Selection of the logistics machine** - a conventional type and model of logistic machine is selected for the specific logistics system.

2. **Analysis of the real work of the operator**. The real work of the machine in the logistics system is analyzed for one 8-hour production (service) shift. Considered is the real work-time Tr as part of the shift time Ts.

$$A = \frac{T_r}{T_s} \tag{1}$$

$$T_r = \sum_{z=1}^{Z} \sum_{i=1}^{N} T_z^i \quad (2)$$

where:
A-level of business $A=[0-1]$

T_z^i – time f the i^{-th} work cycle of the logistics machine for the z^{-th} type of work.$(i=1,2,\ldots,N)$ $(z=1,2,\ldots,Z)$;

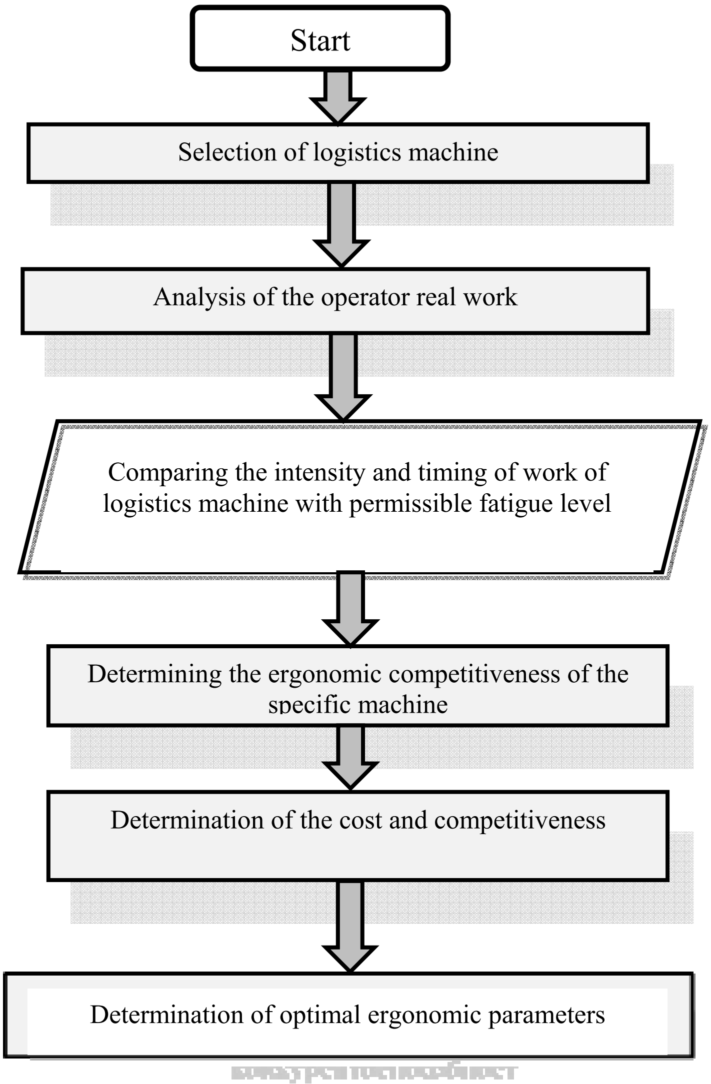

Figure 3. Scheme of the methodology for assessing ergonomic requirement

There are standards for the working regimes of the produced logistics machines. For example, in Bulgaria the produced cranes have the mode of operation regulated by BDS ISO 4301-1 depending on the work time duration and the capacity use of the loaded mechanism. For the purposes of this study it can be taken into account only the duration of the work time i.e. the mode of operation of the crane shall be determined by taking into account factors from the "class of use" group. It is determined by the total number of operating cycles of the crane for the full period of its operation. From the point of view of classification it is considered that the working cycle starts when the load is ready to be lifted and ends when the crane is ready to pick up the next load. The total number of operating cycles is the sum of all duty cycles for the set period of operation of the crane. The range of the possible number of operating cycles is divided into ten classes of use - Table. 1. (Krastanov K. 2012). The mode of operation based on loading capacity is not significant because it does not matter for the operator if a load is lifted with different load capacity.

TABLE 1
CLASSES OF CRANE USE

Class of use	Max. number of the work cycles	Notes
U0	1,6 x10 4	Rare use
U1	3,2 x10 4	
U2	6,3x10 4	
U3	1,25 x 103	
U4	2,5 x10 5	Regular use with weak intensity
U5	5 x10 5	Regular use with average intensity
U6	1x10 6	Regular use with high intensity
U7	2 x 10 6	Intensive use
U8	4 x 10 6	
U9	up 4x106	

From the above it is obvious that the running time of the crane is for the entire period of operation, which determines the use of data in this case only as a guide.

III. COMPARISON OF INTENSITY AND WORKING TIME OF A LOGISTICS MACHINE WITH THE ALLOWABLE FATIGUE OF THE OPERATOR (SYSTEM MAN - MACHINE).

At this stage different relationships are determined (coefficients and charts of the ergonomic parameters) for the operator fatigue during the actual work time in one shift and at different levels of ergonomics.

Let Θ reflect the fatigue during working hours as a time during which the operator responds and accumulates fatigue (mental fatigue and physical fatigue), i.e.

$$\Theta(f\sum T_r)=\sum_{i=1}^{I}\delta_i+\sum_{j=1}^{J}\delta_j \qquad (3)$$

where:

δ_i - mental fatigue as a response from the operator's reactions (reducing the concentration, slowed reactions, etc..)

δ_j - physical fatigue including visual fatigue.

It is known that the response time of the operator is determined by the time of the latent (hidden) period of reaction and the time for the action. In (Shirokov A. 2006) a table is shown with values of the latent period of response (Table 2).

TABLE 2.
MEANINGS OF THE LATENCY RESPONSE

Irritant	Analyst	Latent period [ms]
Vibrations	sensitivity	90-220
Noise	hearing	120-180
Lighting	eyesight	150-220
Odor	smell	310-390
Heat, cold	temperature	280-1600
Touch	sensitivity	90-220

The variation of the ergonomic characteristics X vs hours of work could be shown as:

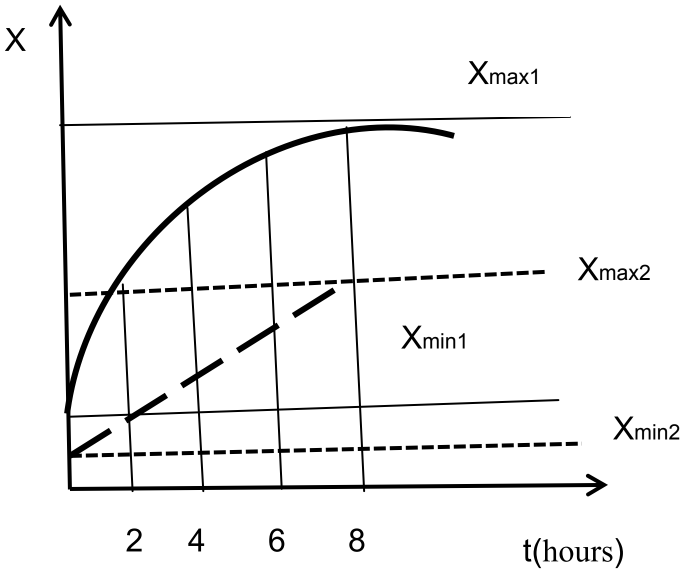

Figure 4. Variation of the X parameters vs work hours

In terms of ergonomics, for logistic machinery it can be said that the fatigue Θ during working hours is a function of time i.e.

$$\Theta = f(X_1(t), X_2(t), \ldots, X_i(t)) \quad (i = 1,2,\ldots,I) \tag{4}$$

where:

$X_i(t)$ - i-th ergonomic characteristics $(i = 1,2,\ldots,I)$

Applying the method of varying the ergonomic competitiveness, the following is obtained:

For $X_i(t) \leq X_i^{min} \rightarrow K_E = 0$

For $X_i(t) > X_i^{min} \rightarrow K_E > 0$

Based on the prepared charts, the field with the min possible values is taken for each parameter. These have to comply with the restrictions in the regulations and company policy on customers. These graphs are also used for the determination of the weighting factor when using the emotional model.

IV. DETERMINATION OF THE ERGONOMIC COMPETITIVENESS

Let Xi (i = 1,2, ..., I) denote the characteristics of the machine that is to be used in the model to evaluate the competitiveness, and Pj (j = 1,2, ..., J) respectively, be the parameters. Furthermore, let KE denote the ergonomic competitiveness of the machine.

Then we have:

$$K_E = f(\varphi_1 X_1, \varphi_2 X_2, \ldots, \varphi_i X_i) \tag{5}$$

where φ_i is the weighting factor of the i-th characteristic relative to competitiveness. Similarly, each characteristic is a function of each of the selected parameters Pj or

$$X_i = f(\omega_1^i P_1, \omega_2^i P_2, \ldots, \omega_j^i P_j) \tag{6}$$

where ω_j^i is the weighting factor of the j-th parameter with respect to the i-th characteristic.

For example let i = 5. Then the characteristics of the logistics machine, essential for the operator in the cabin are:

1. Dimensions of the human body
2. Noise
3. Heat and thermal radiation
4. Lighting
5. Vibrations

Due to the nature of work of the operator it is assumed that the other characteristics (Hazardous materials and radiation, temperature of touchable surfaces, etc.) are not dealt with in this work. Then it follows that:

$X_1(t)$ *- depending on human body dimensions;*

$X_2(t)$ *- depending on the noise;*

$X_3(t)$ *- depending on the heat and radiation;*

$X_4(t)$ *- depending on the lighting;*

$X_5(t)$ *- depending on the vibrations;*

TABLE 3.
TABLE OF WEIGHTS OF CHARACTERISTICS AND PARAMETERS

Mood	Coeff	Feelings	Coeff	Emotions	Scanned points		
					Producer	competitor 1	competitor 2
Ergonomic competitiveness	1	***Human body dimensions***	0,25	seat			
			0	Lighting system			
			0,1	Vibration isolation			
			0,1	Heat insulation and eating			
			0,55	Cabin design			
			0	noise isolation			
	1	***Noise***	0	seat			
			0,1	Lighting system			
			0,2	Vibration isolation			
			0,1	Heat insulation and eating			
			0,1	Cabin design			
			0,5	noise isolation			
	1	***Heat and thermal radiation***	0,1	seat			
			0,15	Lighting system			
			0,1	Vibration isolation			
			0,4	Heat insulation and eating			
			0,15	Cabin design			
			0,1	noise isolation			
	1	***Lighting***	0	seat			
			0,6	Lighting system			
			0	Vibration isolation			
			0	Heat insulation and eating			
			0,4	Cabin design			
			0	noise isolation			
	1	***Vibrations***	0,1	seat			
			0	Lighting system			
			0,5	Vibration isolation			
			0	Heat insulation and eating			
			0,3	Cabin design			
			0,1	noise isolation			

The selected parameters (emotions) are: seat, lighting systems, vibration isolation, insulation and lighting, cabin-design and sound insulation.

To determine the ergonomics of the logistics machine by applying the emotional method (Kubota, N., Wakisaka, S.

2009; Tudjarov B. and all 2009) the following sample table (Table 3) is prepared and the model is solved.

The value obtained is compared with the values of the classes shown below, and the class of ergonomics is defined. On the basis of the defined ergonomics class different specific construction decisions are made.

The ergonomics class is determined by

$$K_m = \frac{E_m}{E} \leq 1 \tag{7}$$

where:

E – machine comfort level for full shift work

E_m – machine comfort level for less than a full shift work.

It is obvious that the interval of variation is 0-1. For this study it is assumed that there exist four ergonomic classes – A, B, C, D (fig.5) i.e.:

Class A - $K_m = 0 - 0{,}25$ *- 2-hour work*

Class B - $K_m = 0{,}25 - 0{,}5$ *- 4-hour work*

Class C - $K_m = 0{,}5 - 0{,}75$ *- 6-hour work*

Class D - $K_m = 0{,}75 - 1{,}0$ *- 8-hour work*

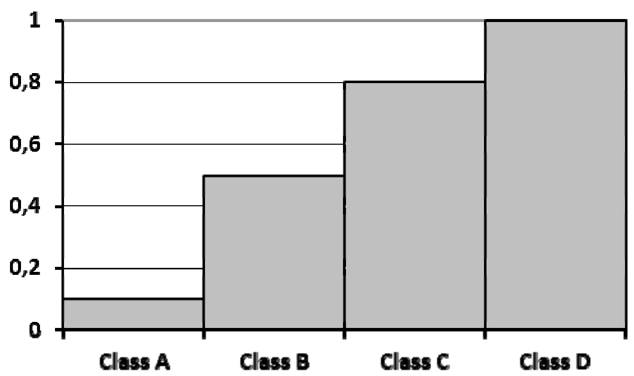

Figure 5. Classes of ergonomics

V. Determination of the cost and competitiveness of the chosen machine.

For the determination of the cost and competitiveness of the chosen machine a ratio is made of parameters to cost, comparison is performed with competing models and area of competitiveness is defined.

Ergonomics is related to the quality of a logistics machine. Applying the approach of (Nikolova I, N. Kazakov. 2001), it follows:

$$K = K_1 + K_2 \tag{8}$$

where:

K_1 - capital investments required to perform the basic technological process. From an ergonomic point of view K_1 are capital investments to achieve the minimum requirements of standards and other normative documents.

K_2 - the additional costs necessary to achieve the desired product quality.

Implementation costs of ergonomic requirements are cost elements of each individual solution to achieve the desired parameters j (j = 1,2, ..., J).

$$K = K_1 + K_2 = \sum_{j=1}^{J} (K_1^j + K_2^j) \tag{9}$$

To determine the competitiveness of logistics machine a factor of ergonomic competitiveness is introduced:

$$Q = \frac{K_E}{C} \tag{10}$$

where:

K_E - ergonomic competitiveness;

C - machine price. *C=f(K)*

Q is determined for our machine, as well as for the major competitors' machines and the location of the machine produced is determined within the area defined by the competitors' machines.

VI. Building a database for the machine components.

Based on the method of functional value analysis (Brimson 2008; Hicks 2000; www.valuebase dmanagement.net), and applying the process of decomposition, the structural model is generated that achieves the necessary cost of the ergonomic solution to the logistic machine (figure 6). The model has a tree structure and is based on the basic principle of the "top-down design":

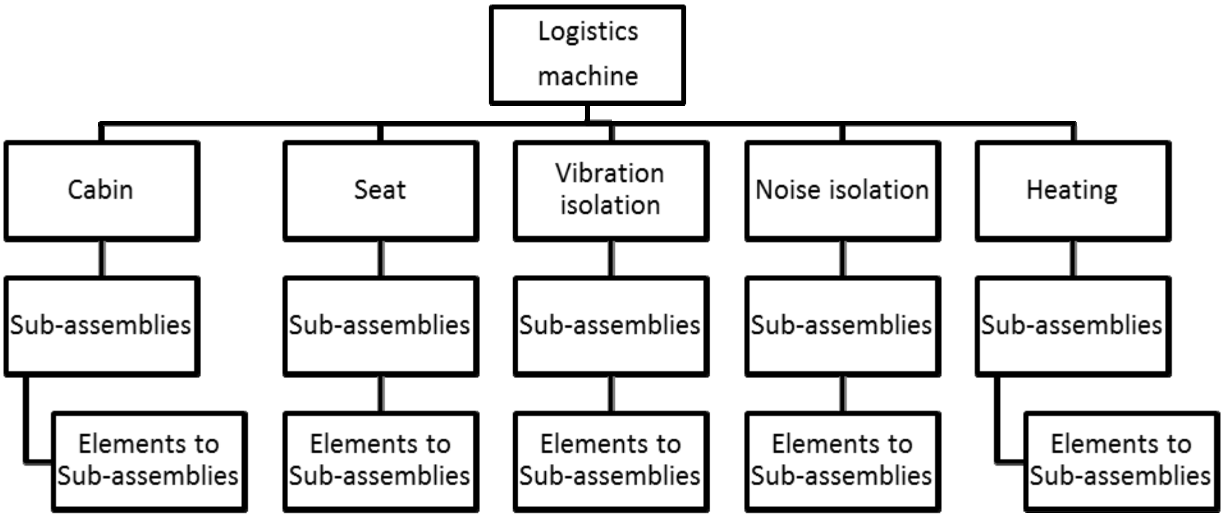

Figure 6. Structural model of a logistics machine

It should be noted that the structural model is a general model and in some specific cases there might be changes. A decomposition is possible for each machine system (logistics machine) according to the elements and providing for a class of ergonomics for: cabin frame, seat, noise and vibration insulation, heating, lighting system etc., i.e. by classification a database is constructed of the ways to achieve a variety of ergonomic solutions. Decomposition can be based on another scheme depending on the individual case and goals. The possible configurations of specific solutions are synthesized for the logistics machine of a given variant, based on the criterion of minimum total cost of each item to achieve the required ergonomics.

Cost of individual solutions and devices for a logistics machine are shown in Table 4.

TABLE 4.
COST PRICE OF THE INDIVIDUAL SOLUTIONS AND DEVICES

Elements		Ergonomic devices (solutions)											
		1				2			…	N			
		Class A	Class B	Class C	Class D	Class A	Class B	Class C	…	Class A	Class B	Class C	Class D
№	Name	Value	Value	Value	Value	Value	Value	Value	…	Value	Value	Value	Value
1	seat	C_{11}^{A}	C_{11}^{B}	C_{11}^{C}	C_{11}^{D}	C_{12}^{A}	C_{12}^{B}	C_{12}^{C}	…	C_{1N}^{A}	C_{1N}^{B}	C_{1N}^{C}	C_{1N}^{D}
2	Cabin structure	C_{21}^{A}	C_{21}^{B}	C_{21}^{C}	C_{21}^{D}	C_{22}^{A}	C_{22}^{B}	C_{22}^{C}	…	C_{2N}^{A}	C_{2N}^{B}	C_{2N}^{C}	C_{2N}^{D}
3	Vibration insulation	C_{31}^{A}	C_{31}^{B}	C_{31}^{C}	C_{31}^{D}	C_{32}^{A}	C_{32}^{B}	C_{32}^{C}	…	C_{3N}^{A}	C_{3N}^{B}	C_{3N}^{C}	C_{3N}^{D}
4	Noise insulation	C_{41}^{A}	C_{41}^{B}	C_{41}^{C}	C_{41}^{D}	C_{42}^{A}	C_{42}^{B}	C_{42}^{C}	…	C_{4N}^{A}	C_{4N}^{B}	C_{4N}^{C}	C_{4N}^{NN}
5	Heating	C_{51}^{A}	C_{51}^{B}	C_{51}^{C}	C_{51}^{D}	C_{52}^{A}	C_{52}^{B}	C_{52}^{C}	…	C_{5N}^{A}	C_{5N}^{B}	C_{5N}^{C}	C_{5N}^{D}
6	Lighting system	C_{61}^{A}	C_{61}^{B}	C_{61}^{C}	C_{61}^{D}	C_{52}^{A}	C_{52}^{B}	C_{52}^{C}	…	C_{5N}^{A}	C_{5N}^{B}	C_{5N}^{C}	C_{5N}^{D}

It is assumed in this work that each device has N number of solutions and each solution consists of various combinations of elements for classes A-D at the appropriate cost.

VII. Determination of optimal ergonomic parameters of the machines

Optimal ergonomic parameters are obtained by searching for a minimum cost for the required class of ergonomics (A, B, C, D) of all possible combinations of solutions in the class i.e.

$$\sum_{j=1}^{J} C_{jn}^{\xi} \rightarrow min \tag{11}$$

where: $A \cap B \cap C \cap D$; $(n=1,2,\ldots,N)$

The boundary conditions are defined for the specific case and the policy of the manufacturer. Under certain conditions and policies, the decisions could be not only from one class of ergonomics (A or B or C or D) but rather combinations of different groups. It is advisable to draw preliminary lists of all possible configurations according to Table 1.

Reducing the overall ergonomic requirement of the logistics machine according to company policy is achieved by replacing a cheaper machine configuration with a new decision with higher ergonomic requirement and machine synthesis is performed i.e. generating of the whole machine according to the elements of table1. As a result, lists of all the possible configurations of the machine are obtained that enable the selection of the most appropriate configuration.

Conclusions

1. A methodology is proposed for evaluating the ergonomic requirement in logistics equipment, by taking into account their work time.
2. To facilitate the practical application, four classes of ergonomics are introduced - A, B, C, D depending on the time of their work.
3. Proposed is the emotional method for determination of the required ergonomics of logistics machines.

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